

THE ANTENNA LABORATORY

RECEIVED
#2

RESEARCH ACTIVITIES in ---

Automatic Control Antennas Echo Area Studies
Microwave Circuits Astronautics E.M. Field Theory
Terrain Investigation Radar System Analysis
Wave Propagation Submillimeter Applications

X 66 35164

FACILITY FORM 602

(ACCESSION NUMBER)

32

(PAGES)

CR 68634

(NASA CR OR TMX OR AD NUMBER)

(THRU)

2A

(CODE)

07

(CATEGORY)

The Short Term ($\tau_{\max} = 3$ Sec)
Autocorrelation Function
of Echo II-Reflected Signals

by
Stephen L. Zoway

Contract Number NA55-9507

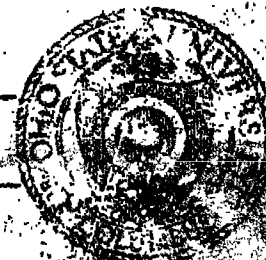
Available to NASA OFF
NASA Contract Data

1878-8

31 December 1964

Prepared for:
National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

Department of ELECTRICAL ENGINEERING



THE OHIO STATE UNIVERSITY
RESEARCH FOUNDATION
Columbus, Ohio

WALL STREET JOURNAL
LIBRARY

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The Government has the right to reproduce, use, and distribute this report for governmental purposes in accordance with the contract under which the report was produced. To protect the proprietary interests of the contractor and to avoid jeopardy of its obligations to the Government, the report may not be released for non-governmental use such as might constitute general publication without the express prior consent of The Ohio State University Research Foundation.

Qualified requesters may obtain copies of this report from the Defense Documentation Center, Cameron Station, Alexandria, Virginia. Department of Defense contractors must be established for DDC services, or have their "need-to-know" certified by the cognizant military agency of their project or contract.

REPORT 1878-8

REPORT

by

THE OHIO STATE UNIVERSITY RESEARCH FOUNDATION
COLUMBUS, OHIO 43212

Sponsor National Aeronautics and Space Administration
 Goddard Space Flight Center
 Glen Dale Road
 Greenbelt, Maryland 20771

Contract Number NAS5-9507

Investigation of Tracking, Receiving, Recording and Analysis
 of Data from Echo Satellite

Subject of Report The Short Term ($\tau_{\max} = 3$ Sec) Autocorrelation
 Function of Echo II-Reflected Signals

Submitted by Stephen I. Zolnay
 Antenna Laboratory
 Department of Electrical Engineering

Date 31 December 1964

ABSTRACT

This report is one of a series dealing with various aspects of Echo-reflected signals. The purpose of this report is to present the autocorrelation function of the signals received during selected Echo II revolutions from revolution numbers 2000-3500. Some Echo I data are also included. The SPCR (specular-to-scattered power ratio) is defined and computed from the ACF's. Consideration is given to some of the errors involved in obtaining the ACF's and the effect of these errors on the final results. On basis of the large amount of data presented it is found that the SPCR for Echo II is 6-7 db, 5-6 db for Echo I. The possible ranges in the values of the SPCR, based on the possible ranges of the errors in the process of analysis, are also computed and tabulated.

TABLE OF CONTENTS

	<u>Page</u>
I. INTRODUCTION	1
II. EXPERIMENTAL RESULTS	6
III. SUMMARY	11
ACKNOWLEDGMENTS	26
REFERENCES	27

BLANK PAGE

THE SHORT TERM ($\tau_{max} = 3$ SEC) AUTOCORRELATION
FUNCTION OF ECHO II-REFLECTED SIGNALS

I. INTRODUCTION

This report is one of a series dealing with various aspects of Echo-reflected signals. There are actually two series of reports. The data for the earlier series were primarily obtained from Echo II-reflected signals before revolution 2000, the data for the present series were selected from Echo I revolutions between 2000 and 3500. The two series of reports can be regarded as a single coherent unit covering the orbital lifetime of Echo II to the present. Some of the subjects considered in these series are amplitude scintillations, echo area, power spectral density, probability density, autocorrelation, depolarization effects, and the scattering function of Echo.

The data for the present series are taken from five Echo II revolutions: 2626, 2653, 2816, 3040, 3483. The data collected on these passes are representative of all data collected during the period covering revolutions 2000-3500. Data collected on two Echo I revolutions (18,166 and 18,966) that occurred during this same period are also included for comparison. The purpose of this report is to present the autocorrelation functions obtained from the recent experimental data.

The signals were cw at 2260 mc/sec and originated from the Collins Space Communications Facility at Dallas, Texas. They were reflected by the orbiting Echo satellites and received by the Satellite Communication Center of the Antenna Laboratory, The Ohio State University. Detailed description of both sites can be found in the references.^{1,2} A simplified block diagram of the receiving and recording system is included here for completeness (see Fig. 1 which is mostly self-explanatory). Phase-locked demodulators were used as linear detectors. In case of a cw signal whose amplitude was constant during transmission, the AM output of the linear detector would be a steady dc value proportional to the level of received power. Figure 2 shows a sample of the recordings of the AM output of the detector which is typically observed for all Echo-reflected data. It can be seen that the instantaneous received power level is not a steady dc value; rather, the received power level is strongly fluctuating between the observable extremes of noise and saturation levels. A statistical method of analyzing data such as shown in Fig. 2 is to obtain its

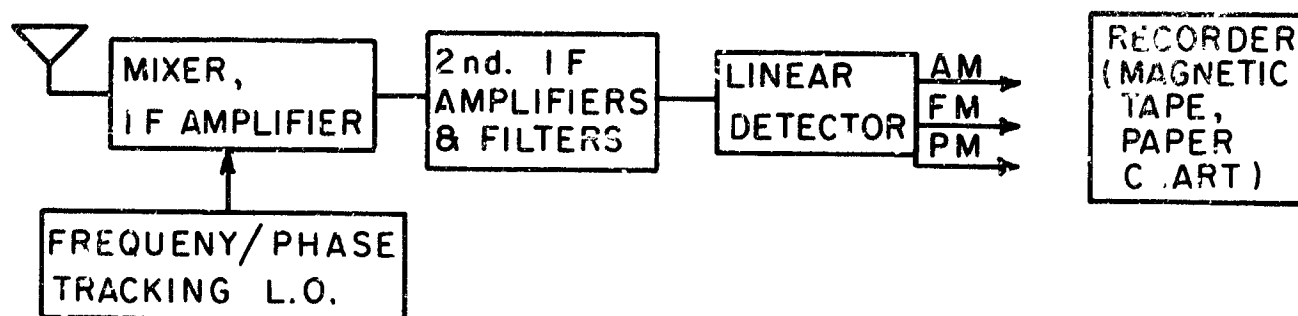


Fig. 1. Simplified block diagram of receiving and recording system.

correlation function. The details of data reduction to obtain the autocorrelation function have been treated elsewhere.³

Correlation by definition is a measure of the degree of interdependence between two quantities. Hence, the autocorrelation function is one that expresses the degree of interdependence between a quantity -- such as the instantaneous value of the received power -- and itself. The quantities whose interdependence is to be measured are functions of time; their resulting ACF is a function of the relative time delay between them. In the present case the maximum time delay, τ_{\max} , was restricted to 3 sec, which was 10% of the sample length, T ; hence the descriptive name -- short-term autocorrelation function.

Mathematically, the autocorrelation function ACF is related as

$$(1) \quad \phi(\tau) = \lim_{T \rightarrow \infty} \frac{1}{T} \int_{-T/2}^{T/2} f(t) f(t+\tau) dt,$$

where $f(t)$ corresponds to the AM output of the linear detector, which in turn is proportional to the instantaneous level of the received power. The variations in this level can be regarded as a modulation on the amplitude of the cw signal resulting from its transmission through the Echo channel. Should the received power level cause a constant dc output from the linear detector corresponding to the case of an unmodulated cw signal, one would obtain an ACF of constant amplitude. The interpretation of such an ACF is that there is no time dependence in the data. Should the received power level cause a dc output (which is randomly varying about some average value) from the detector, corresponding to

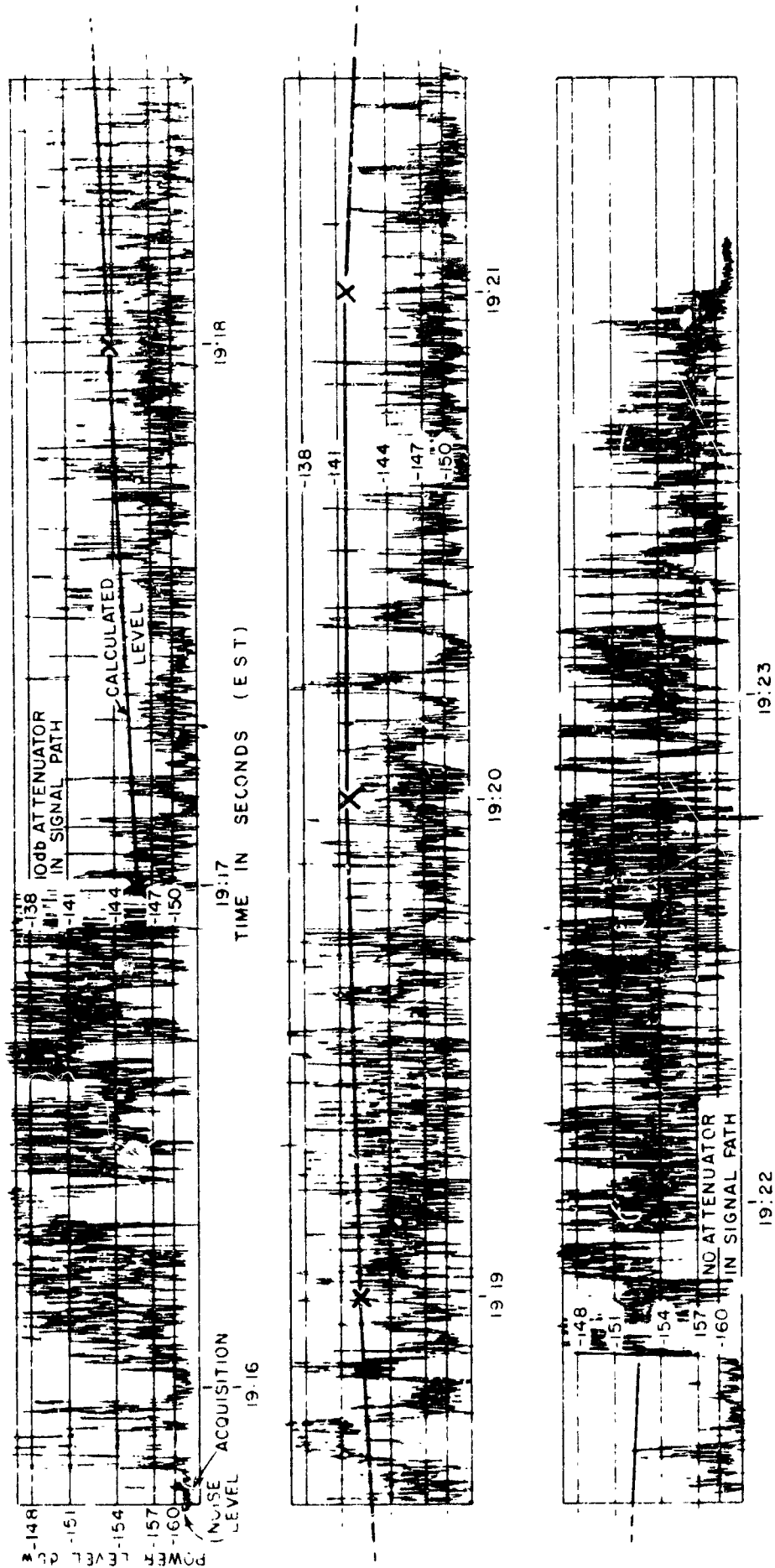


Fig. 2. Typical instantaneous signal strength recording Echo II revolution 2626.

the case of an extremely noisy signal, one would obtain an ACF whose amplitude would be maximum at no time delay, and an average value, corresponding to the dc average, for any time delay other than zero. That is, with the addition of an impulse of $\tau = 0$, there would result an ACF similar to the previous case. The interpretation of such an ACF is that the portion of the data causing the impulse in the ACF is very strongly time dependent. The two cases are shown in Fig. 3.

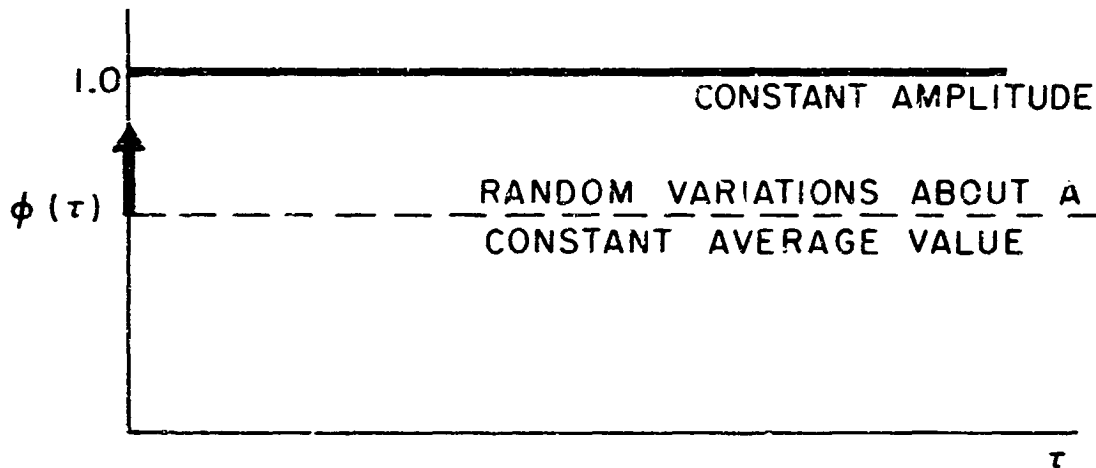


Fig. 3. Normalized autocorrelation functions of a constant amplitude function and of one of random variations about a constant amplitude.

The ACF's of Echo-reflected signals fall between the above two extremes. This indicates that when a steady amplitude signal is passed through the Echo channel it acquires an amplitude modulation by the noise present in the channel. Most of the noise probably originates at the target since the Echoes are regarded as essentially spherical in shape but with small-scale surface roughness. The reflecting characteristic of such a surface is shown in Fig. 4. The specular component is from the spherical shape and the scattered components are from the numerous surface irregularities. Both Echoes are moving and in addition to the orbital motion a spin is claimed for Echo II; thus the scattered components will continually vary in amplitude. Were the reflector perfectly smooth, its motion, including spinning, would not give rise to scattered components of varying amplitudes; and were the reflector stationary the roughness of its surface again would not produce variations in the amplitude of the total reflected signals. Thus, the two proposed mechanisms, rough surface and moving target, combine to yield a total reflected signal which is composed of two parts: an average steady component due to specular reflection and a fluctuating component due to scattering.

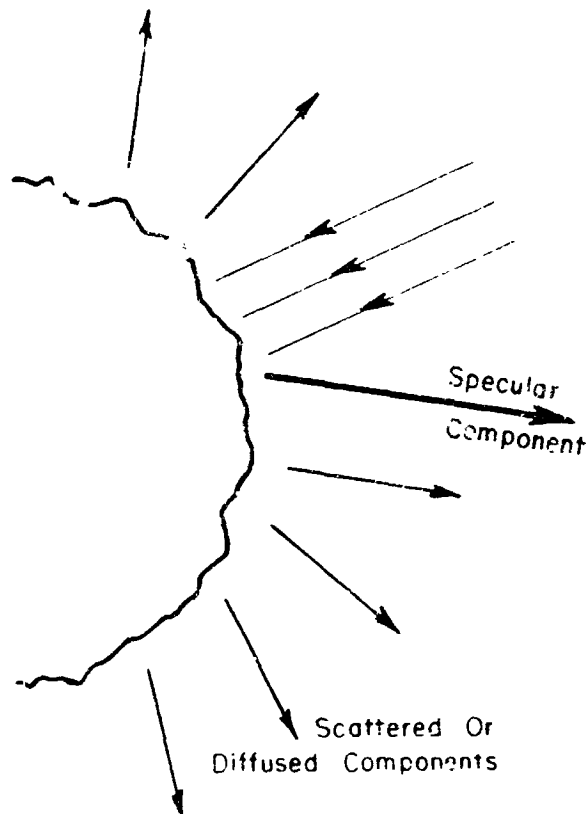


Fig. 4. A model of a spherical reflector with surface roughness.

The average level of the received power at the detector output is not correlated with the fluctuating component, hence the ACF of $\tau = 0$ is the sum of the mean square value of the fluctuating component and the mean square value of the average level, normalized to unity. As τ is increased, because of the noisy nature of the fluctuating component the correlation of this component with itself decreases. Eventually, the value of the ACF will only be proportional to the mean square value of the average level $\langle y \rangle^2$. This fact provides a convenient method to obtain the ratio of the specular and scattered powers:⁴

$$(2) \quad \frac{\text{specular power}}{\text{scattered power}} = \frac{\langle y \rangle^2}{1 - \langle y \rangle^2} = \text{SPCR}.$$

Equation (2) will be used to express the specularity of the reflection from the satellites. It follows that a large value of specularity implies a smooth reflecting surface and vice-versa. Presumably the specularity is a function of the bistatic angle of scattering measured at the satellite, and the position of the flare spot on the reflector. The position of the flare spot, in turn, is a function of the orbital motion and the possible

... of the satellite. These effects cannot be evaluated here unless some assumptions are made about the possible rotation of the satellite; hence, the specularity will be computed using Eq. (2) directly.

II. EXPERIMENTAL RESULTS

The data on the instantaneous power level were stored on magnetic tape whose frequency resolution was 1-1.2 kc/sec, which is abundantly adequate to record all frequencies present in the amplitude scintillations of the received power. The magnetic tape recording was transferred to a scope of oscillographic type. The time on the chart was synchronized to the actual time of the magnetic tape. Every second on the chart was accurately divided into 50 parts. The trace on the chart was smoothed by drawing a line through the center of the trace but preserving details that were slower than 50 per second. A linearization curve was prepared from the calibration curve at the beginning of the chart that was made in terms of deflection at the output of the receiving system per db change at the 30 mc/sec input. This linearization curve was accurately approximated with polynomials (highest order used: tenth) which in turn were used to effectively remove most of the nonlinearities from the data. The chart recording was sampled 50 times per second, thus the data were digitized. Equation (1) was suitably modified for the digitized data:

$$(3) \quad \phi(\tau) = \frac{1}{N} \sum_{X=1}^N f_X i_X + \tau,$$

where N is the number of digitized data points. N was on the order of 1500, corresponding to sample lengths of 30 seconds. Equation (3) was programmed on an IBM 7094 and the statistical estimate of the ACF given in Eq. (1) was obtained.

Both the sampling rate and the sample length impose limitations on the accuracy of the estimate of the ACF. If one requires at least four points to establish the frequency of a given waveform then the sampling rate of 50/sec imposes an upper limit of 13 cps on the frequency resolution inherent in the ACF's. If the original data contained a periodic component with angular frequency ω_0 , then it follows that the ACF will also contain the same periodic component as the sample length is increased without limit. For finite sample lengths, however, there will be an error in the ACF and the magnitude of this error is inversely proportional to the sample length T. Solodovnikov⁵ treats this problem and recommends that T must be at least $10T_0$ where $T_0 = 2\pi/\omega_0$ and

The maximum time delay should be less than $2T_0$ for an error not exceeding 2%. All time delays used in generating the ACF's in this report were conservatively restricted to $1T_0$. Using Solodovnikov's results the finite sample lengths impose a lower limit of 1/3 cps on the frequency resolution inherent in the ACF's. These two limits of frequency resolution, 1/3 to 13 cps, are very important considerations when one attempts to obtain the power spectral density function from the ACF.

The finite length T also imposes a limit on the accuracy with which the mean square value (that value to which all the graphs are apparently asymptotic) of the ACF can be determined. Several articles in the literature deal with expected statistical errors in measurements on random functions, e.g., Reference 6. The absolute mean square error, $\sigma_m^2(T)$, in the measurement of the mean of the random process is given by⁶

$$(4) \quad \sigma_m^2(T) = \frac{2}{T} \int_0^T \left(1 - \frac{\tau}{T}\right) [R_y(\tau) - \langle y \rangle^2] d\tau.$$

In the case of the ACF of Echo-reflected signals, the second quantity under the integral sign can be approximated by⁴

$$(5) \quad R_y(\tau) - \langle y \rangle^2 \doteq e^{-a\tau},$$

where a is the slope of the ACF at $\tau = 0$ and it can best be determined experimentally. Thus, Eq. (4) reduces to

$$(6) \quad \sigma_m^2(T) = \frac{2}{T} \int_0^T \left(1 - \frac{\tau}{T}\right) e^{-a\tau} d\tau,$$

which can be evaluated as

$$(7) \quad \sigma_m^2(T) = \frac{2}{a^2 T^2} (aT + e^{-aT} - 1).$$

The term e^{-aT} in Eq. (7) for $a \geq 1/4$ and $T = 30$ is less than 0.0006; hence it is negligibly small in comparison with unity and it will be dropped. Equation (7) reduces to

$$(8) \quad \sigma_m^2(T) = \frac{30a-1}{450a^2} .$$

Equation (8) is an expression for the absolute mean square error in the measurement of the true mean evaluated for use with the ACF's in this report. Since all ACF's are normalized to unity, an expression for the relative mean square error is wanted. This expression is simply

$$(9) \quad \epsilon_1 = \frac{\sigma_m^2(T)}{\langle y \rangle^2} = \frac{30a-1}{450a^2} \frac{1}{\langle y \rangle^2} .$$

Figures 5-11 show the ACF of Echo-reflected signals. In all these figures are shown individual ACF's that were prepared from data obtained at different times during the revolution indicated. On these individual ACF's the true mean square value $\langle y \rangle^2$ is estimated. In all instances the last graph for a given figure shows all the ACF's plotted to the same scale on a single graph. On this last graph the experimentally determined maximum and minimum slopes are indicated, together with the corresponding estimated values of $\langle y \rangle^2$. In Figs. 5-11 there appears to be a considerable amount of uncertainty as to the value of $\langle y \rangle^2$. The expanded scale is somewhat misleading, however. To obtain a quantitative evaluation of the magnitude of uncertainty involved in estimating $\langle y \rangle^2$, the maximum and minimum values of $\phi(\tau)$ were measured for each graph and the difference was expressed in percentage of the arithmetic average of the maximum and minimum values of $\phi(\tau)$. Thus the maximum percentage error, ϵ_2 , in estimating the true mean square average value is given by

$$(10) \quad \epsilon_2 = 2 \frac{\phi_{\max}(\tau) - \phi_{\min}(\tau)}{\phi_{\max}(\tau) + \phi_{\min}(\tau)} \times 100.$$

Equation (10) is labeled as maximum percentage error since in many instances an obviously quite accurate estimate can be obtained for $\langle y \rangle^2$, e.g., Fig. 5(c). Table I lists the $\phi_{\max}(\tau)$ and $\phi_{\min}(\tau)$ values and the evaluated ϵ_2 for all ACF's. In obtaining $\phi_{\max}(\tau)$ and $\phi_{\min}(\tau)$ values τ was restricted to the interval: $0.5 \leq \tau \leq 2.5$. It can be seen from Table I that the most often occurring values for ϵ_2 are 5 and 10; and 25 out of 28 entries are 10 or less. Thus the arithmetic average of all ϵ_2 is taken to be the representative value; this average is seven per cent.

TABLE I
MAXIMUM PERCENTAGE ERROR, ϵ_2 , IN
ESTIMATING THE TRUE MEAN SQUARE
AVERAGE VALUE OF THE ACF'S

Revo- lution Number	a			b			c			d			e		
	$\phi_{\max}(\tau)$	$\phi_{\min}(\tau)$	ϵ_2	$\phi_{\max}(\tau)$	$\phi_{\min}(\tau)$	ϵ_2	$\phi_{\max}(\tau)$	$\phi_{\min}(\tau)$	ϵ_2	$\phi_{\max}(\tau)$	$\phi_{\min}(\tau)$	ϵ_2	$\phi_{\max}(\tau)$	$\phi_{\min}(\tau)$	ϵ_2
2626	.84	.76	10	.85	.79	7	.83	.79	5	--	--	--	--	--	--
2653	.84	.80	5	.86	.79	8	.87	.77	12	.84	.76	10	.83	.80	4
2816	.87	.84	3	.86	.83	4	.82	.76	8	.88	.85	3	.85	.80	6
3040	.83	.79	5	.84	.77	9	.83	.75	10	.88	.81	8	.87	.82	6
3483	.78	.69	12	.82	.78	5	.81	.73	10	.83	.77	8	--	--	--
18166	.79	.68	15	.72	.65	10	.87	.79	10	.83	.79	5	--	--	--
18966	.87	.82	6	.88	.83	5	.84	.75	7	--	--	--	--	--	--

One can now utilize Eq. (2) to obtain the SPCR, and have a quantitative feeling for the accuracy of the values obtained. Table II lists the $\langle y \rangle^2$ values and the SPCR's. The latter values are given in db.

TABLE II
MEAN SQUARE AVERAGE VALUES OF ACF'S
AND ESTIMATES OF SPECULAR-TO-SCATTERED
POWER RATIOS

Revo- lution Number	a		b		c		d		e	
	$\langle y \rangle^2$	SPCR	$\langle y \rangle^2$	SPCR	$\langle y \rangle^2$	SPCR	$\langle y \rangle^2$	SPCR	$\langle y \rangle^2$	SPCR
2626	.81	6.3	.81	6.3	.80	6.0	-	-	-	-
2653	.82	6.6	.83	6.9	.81	6.3	.78	5.4	.81	6.3
2816	.86	7.9	.85	7.4	.79	5.8	.87	8.1	-	-
3040	.82	6.4	.80	5.9	.77	5.3	.83	6.7	.85	7.5
3483	.74	4.6	.82	6.4	.74	4.6	.79	5.8	.64	2.5
18166	.72	4.1	.68	3.3	.84	7.2	.81	6.3	.66	2.9
18966	.84	7.0	.84	7.2	.81	6.3	-	-	-	-

It appears from Table II that the SPCR of Echo-reflected signals is around 6 db and that on basis of the experimental data utilized there are no apparent large discrepancies between the SPCR's obtained from Echo I and from Echo II data.

TABLE III
ERROR IN THE STATISTICAL ESTIMATE
OF THE MEAN SQUARE AVERAGE VALUE

Revolution Number	α_{\max}	$\langle y \rangle^2$	ϵ_1	α_{\min}	$\langle y \rangle^2$	ϵ_1
2626	1.25	.80	6.6%	.50	.81	15.5%
2653	.96	.82	6.9%	.48	.83	15.5
2816	1.25	.79	15.9	.50	.82	15.5
3040	.80	.80	10	.50	.85	14.7
3483	.50	.79	15.7	.40	.74	20.4
18,166	.50	.84	14.7	.24	.81	27
18,966	.60	.84	12.6	.30	.84	7.1

One can now utilize the $\langle y \rangle^2$ values from Table II to evaluate Eq. (9) for the ϵ_1 . Table III lists the maximum and minimum values for the slope and the corresponding values of $\langle y \rangle^2$ and ϵ_1 . It can be seen from Table III that the error in the statistical estimate of the mean square average value is in excess of ten per cent. The procedure used to obtain the values given in Table III assumes that the mean square average can be obtained from experimental data. It was concluded on a basis of the ϵ_2 values given in Table I that the mean square average can be found with an accuracy of $\pm 7\%$. Hence, the ϵ_1 values have an uncertainty associated with them that is also $\pm 7\%$. This uncertainty will not cause any drastic changes in the tabulated ϵ_1 values. It seems, then, that an average value of $\epsilon_1 = 15\%$ will be a sufficiently conservative estimate for the upper limit of the total error involved in obtaining the mean square average value to which the autocorrelation functions are asymptotic. The effect of this 15% error on calculating the SPCR is quite significant. Table IV has been prepared to show the effect of this error. On the basis of the results presented in Table IV one may conclude that the ratio of specularly reflected power and scattered power in an Echo II-reflected cw signal at 2260 mc/sec is about 6-7 db. The few experimental results obtained from representative Echo I returns indicate that the SPCR for that passive satellite is 5-6 db. The effect of the error in obtaining the mean square average value of an ACF prepared from sampled data of finite length can be quite significant. While it is not the purpose to discuss here the theoretical significance of the maximum and minimum SPCR's, it is pointed out that by applying corrections for the error in the statistical estimate of the ACF, maximum values of 15-16 db and minimum values of 1-2 db were obtained for the

SPCR. These are limiting values rather than ones that would closely and consistently agree with the experimental data. This is not to imply, however, that they are not possible values.

TABLE IV
SPECULAR-TO-SCATTERED POWER RATIOS
OF ECHO-REFLECTED SIGNALS

Rev- lution Number	a			b			c			d			e		
	SPCR	SPCR Max	SPCR Min	SPCR	SPCR Max	SPCR Min	SPCR	SPCR Max	SPCR Min	SPCR	SPCR Max	SPCR Min	SPCR	SPCR Max	SPCR Min
2626	6.3	11.2	3.5	6.3	11.3	3.5	6.0	10.6	3.3	-	-	-	-	-	-
2653	6.6	12.1	3.6	6.9	13.2	3.8	6.3	11.3	3.5	5.4	9.4	3.0	6.3	11.3	3.5
2816	7.9	9.2	4.4	7.4	16.3	4.2	5.8	10.0	3.1	8.1	-	4.6	-	-	-
3040	6.4	12.1	3.6	5.9	10.6	3.3	5.3	8.9	2.8	6.7	13.2	3.8	7.5	16.3	4.2
3483	4.6	7.5	2.3	6.4	12.1	3.6	4.6	7.5	2.3	5.8	10.0	3.1	7.5	4.5	1.0
18,166	4.1	6.6	2.0	3.3	5.5	1.4	7.2	14.7	4.0	6.3	11.3	3.5	2.9	5.0	1.1
18,966	7.0	15.0	4.0	7.2	14.7	4.0	6.3	11.3	3.5	-	-	-	-	-	-

III. SUMMARY

This report is one of a series dealing with various aspects of Echo-reflected signals. The data for this report were obtained recently during Echo II revolutions 2000-3500; some data are also included from Echo I-reflected signals which were selected from the same period as when the Echo II data were collected. The purpose of this report is to present the autocorrelation function of the received signals. Some discussion is devoted to the theoretical aspects of the autocorrelation function and the SPCR (specular-to-scattered power ratio) is defined. The method to obtain the SPCR from the ACF is given. A large amount of experimental data is presented. A brief explanation is presented on the method of data reduction and its adaptation to digital, computerized techniques. Consideration is given to some of the errors involved in obtaining the statistical estimate of the ACF and the effect of these errors on the final results. It is found that for the experimental conditions involved in collecting the data the SPCR of Echo II-reflected signals is 6-7 db, and 5-6 db for Echo I-reflected signals. When the results are corrected for the possible errors involved in the statistical process the possible ranges in the SPCR's are obtained. Thus the maximum possible SPCR of an Echo-reflected signal based on available data is 15-16 db and the minimum is a few db.

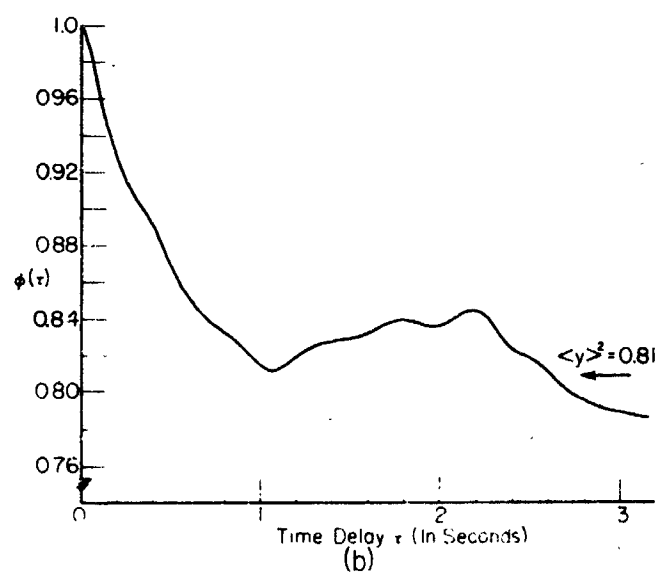
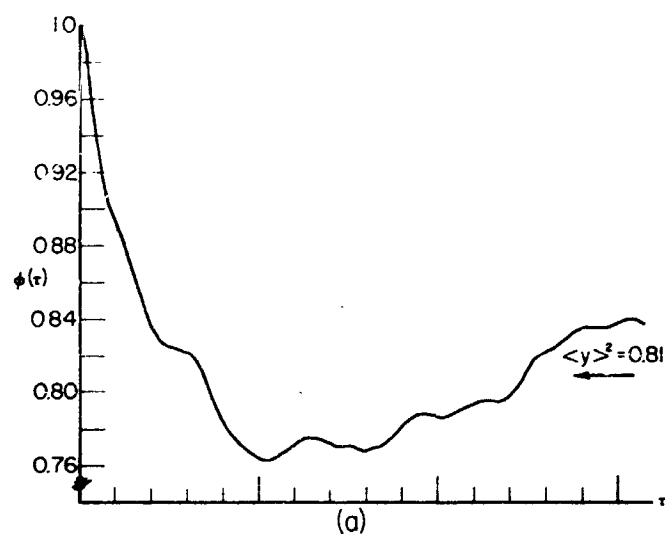


Fig. 5. ACF of Echo II reflected signals. Revolution 2626.

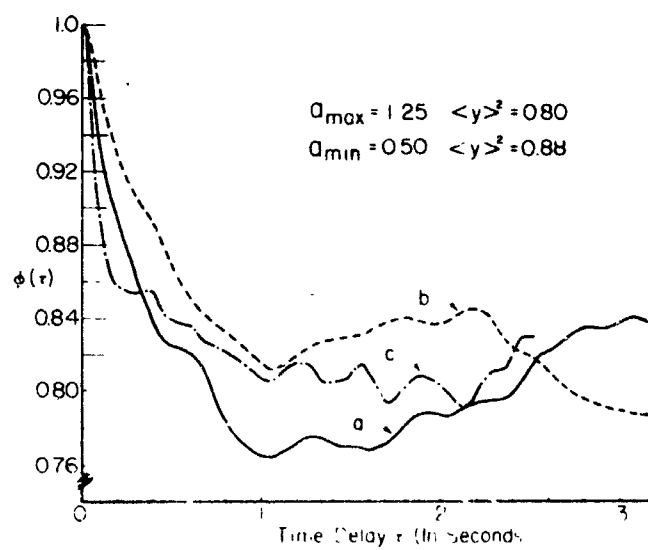
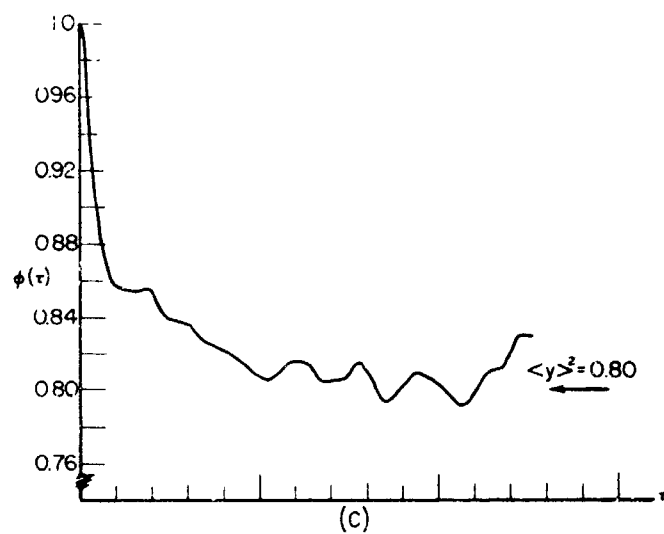


Fig. 5. ACF of Echo II reflected signals. Revolution 2626.

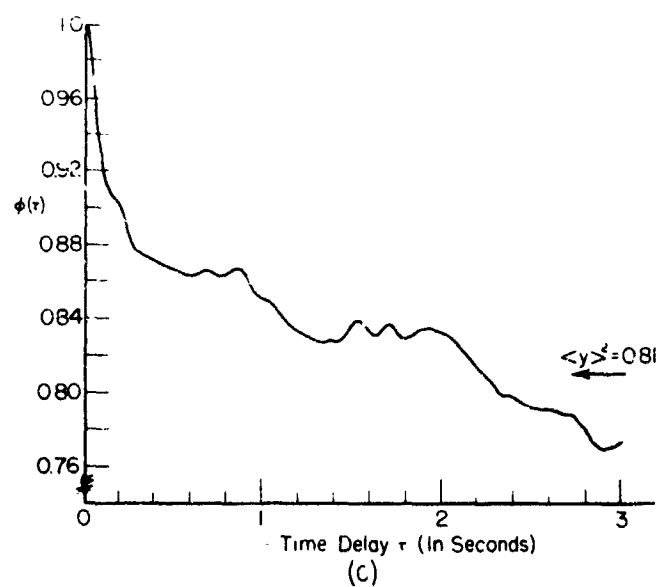
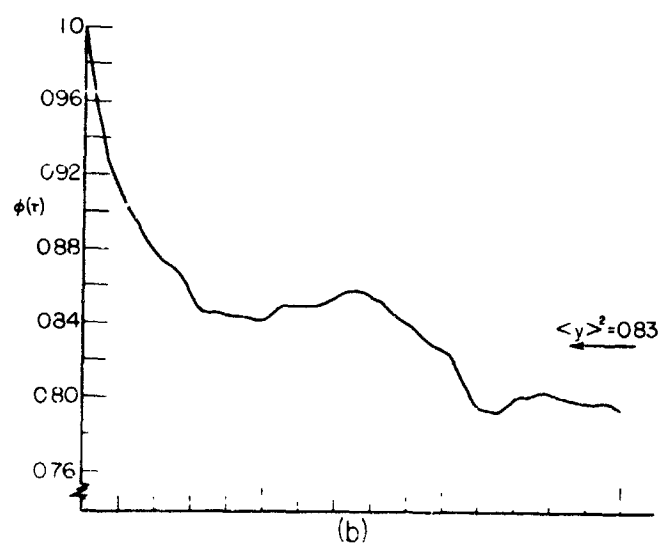
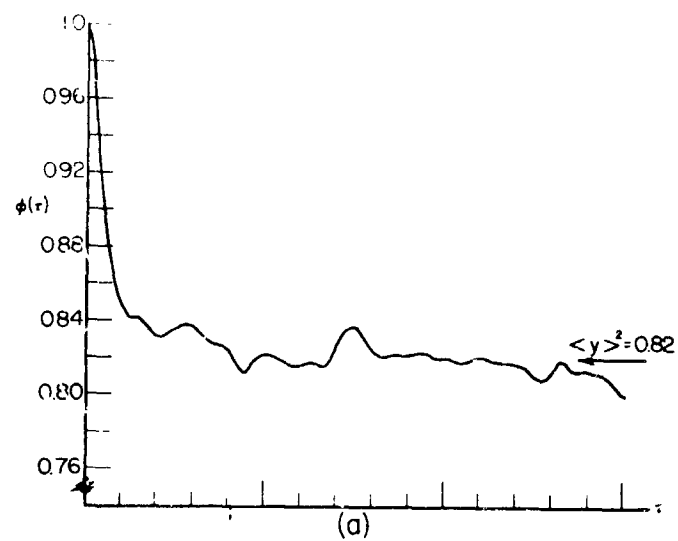


Fig. 6. ACF of Echo II reflected signals. Revolution 2653.

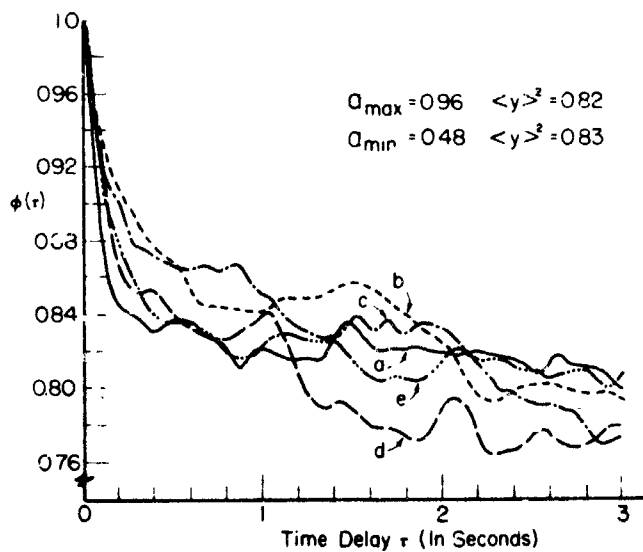
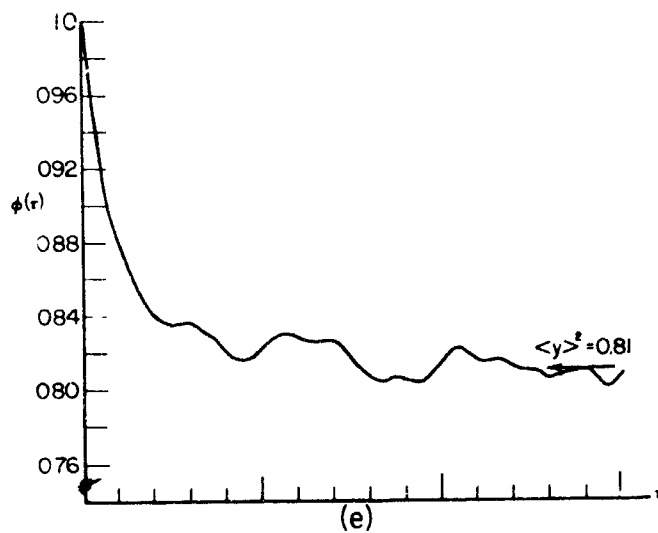
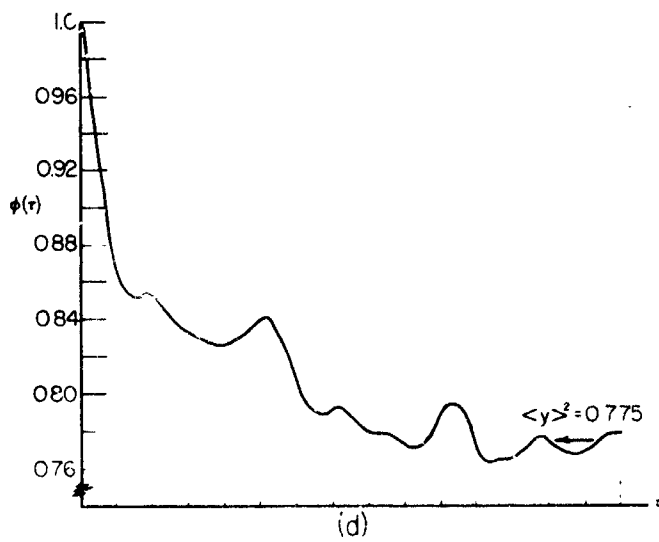


Fig. 6. ACF of Echo II reflected signals. Revolution 2653.

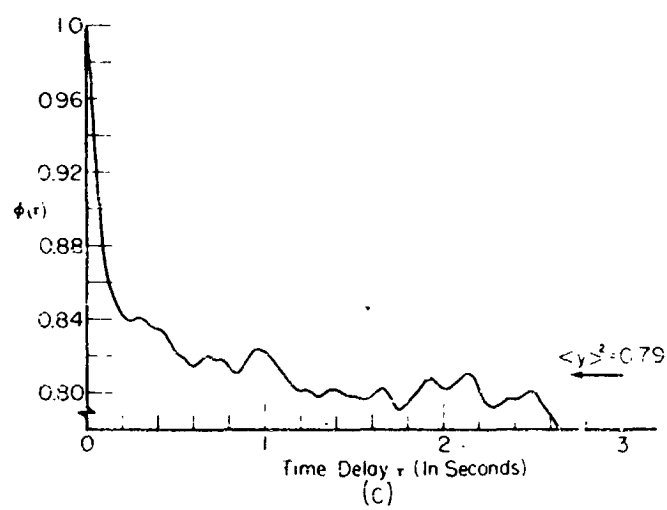
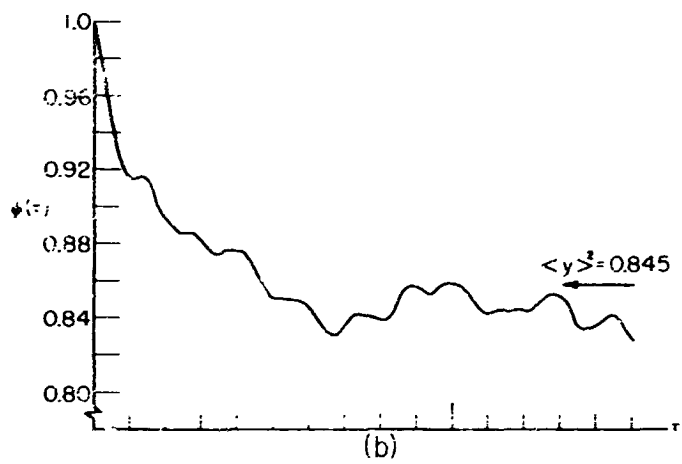
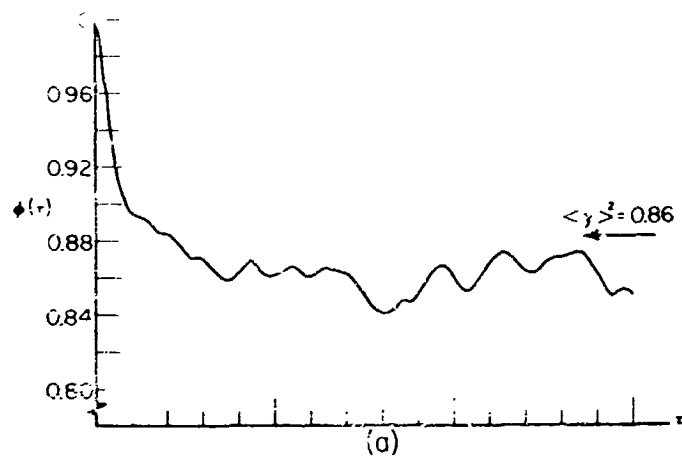


Fig. 7. ACF of Echo II reflected signals. Revolution 2816.

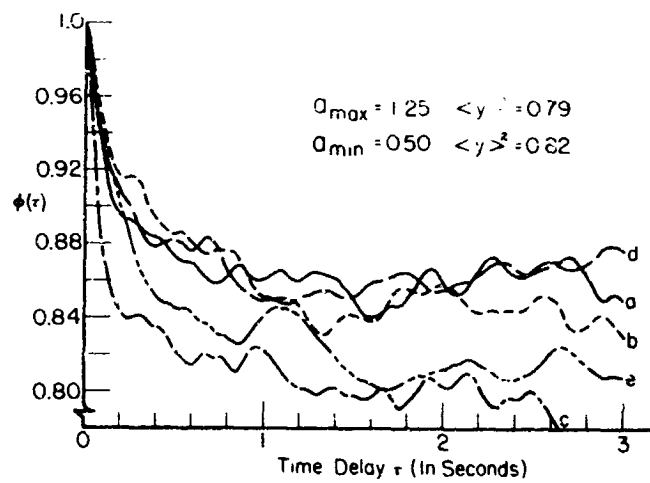
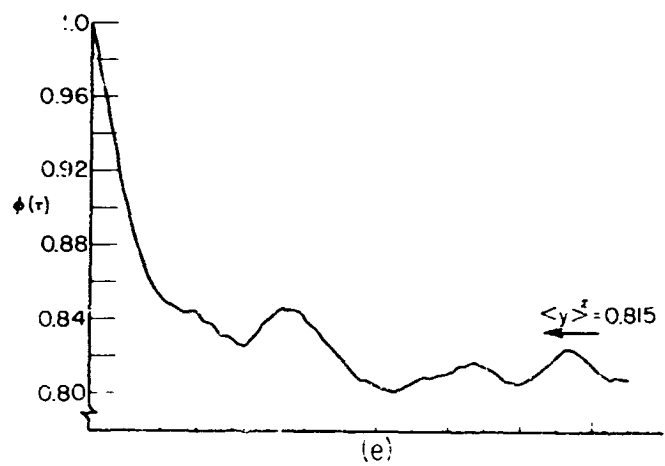
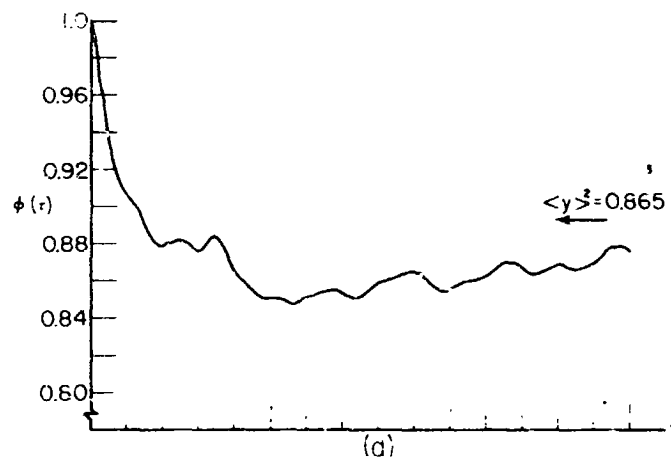


Fig. 7. ACF of Echo II reflected signals. Revolution 2816.

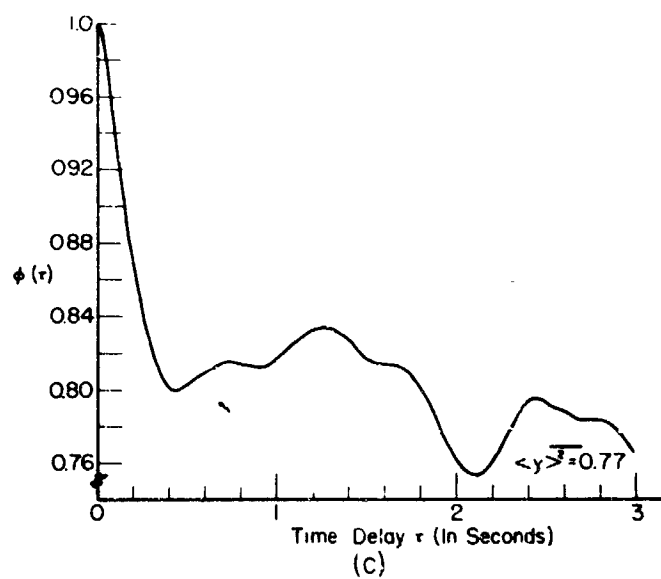
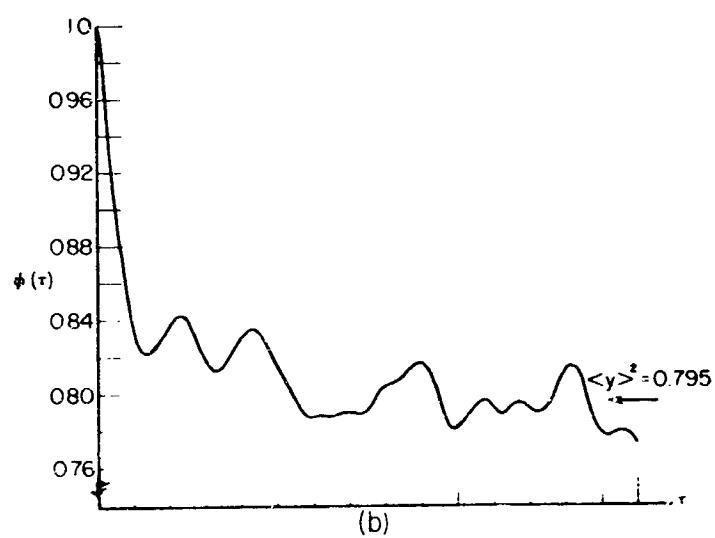
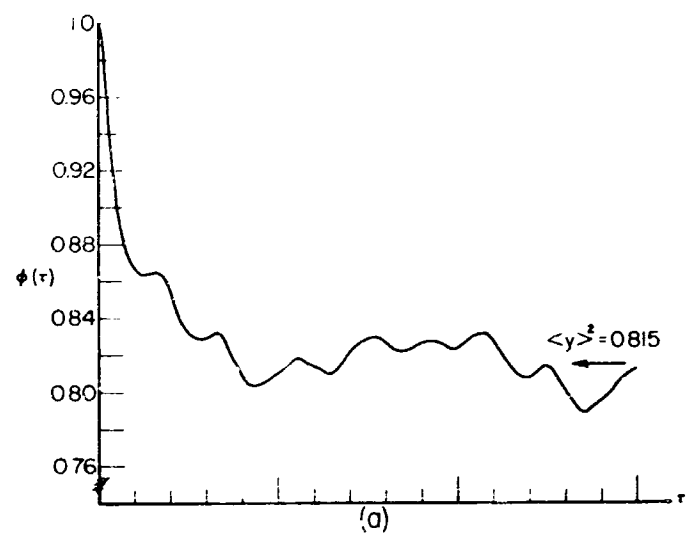


Fig. 8. ACF of Echo II reflected signals. Revolution 3040.

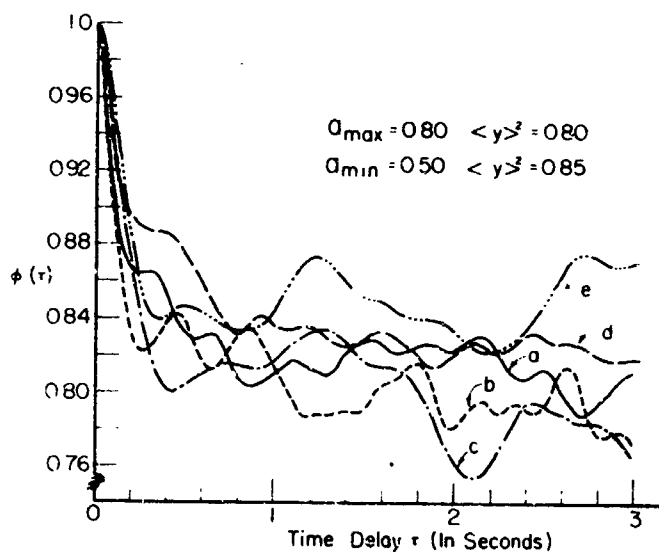
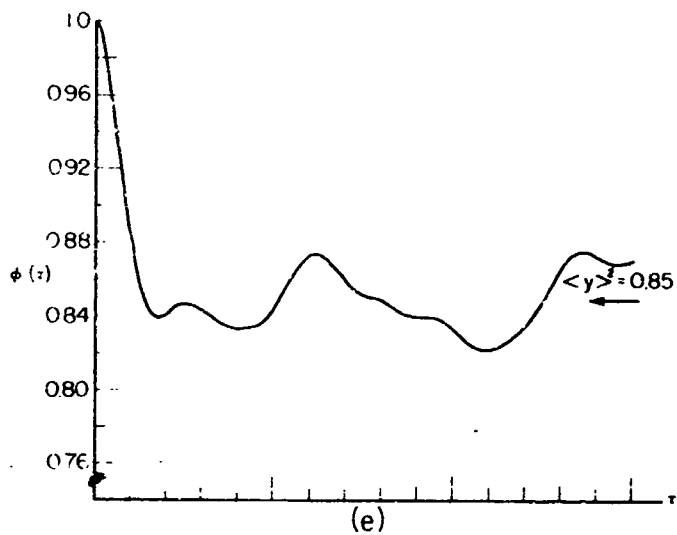
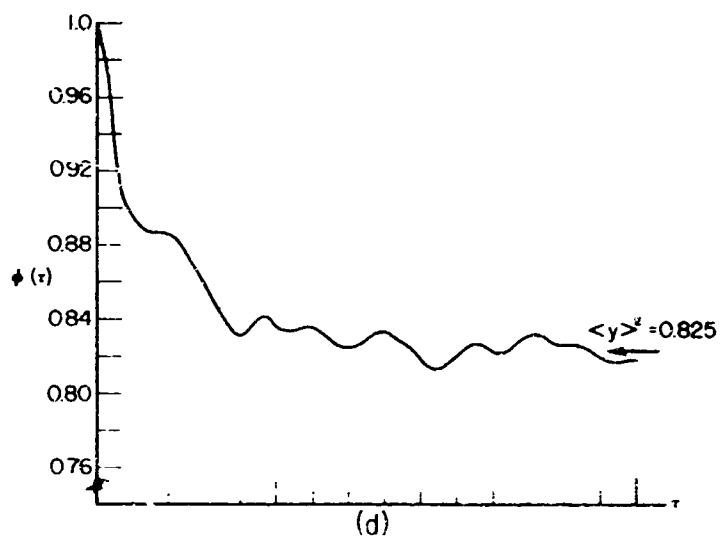


Fig. 8. ACF of Echo II reflected signals. Revolution 3040.

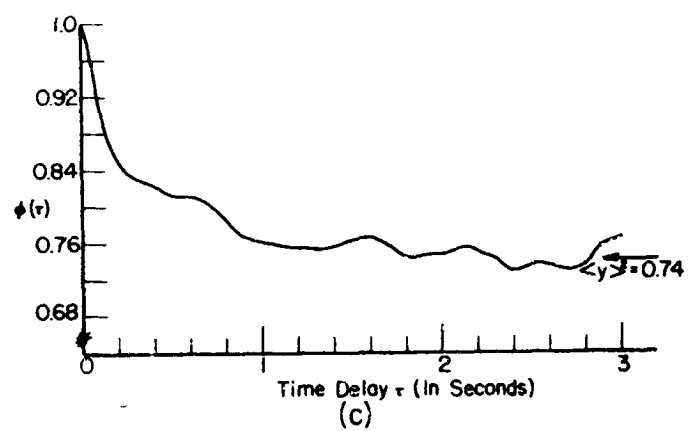
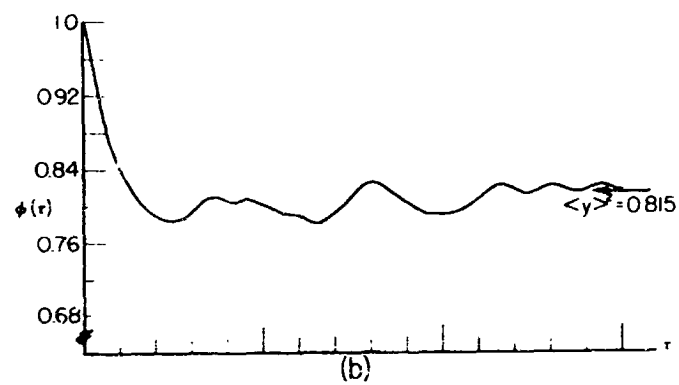
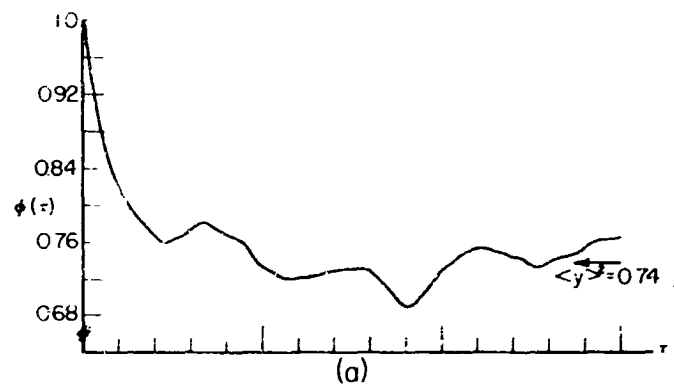


Fig. 9. ACF of Echo II reflected signals. Revolution 3483.

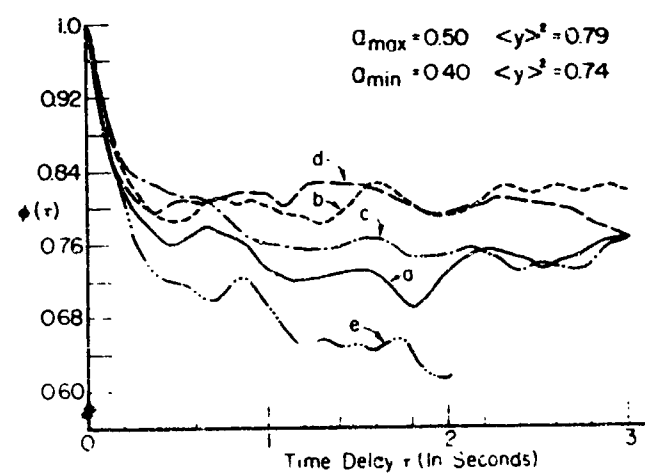
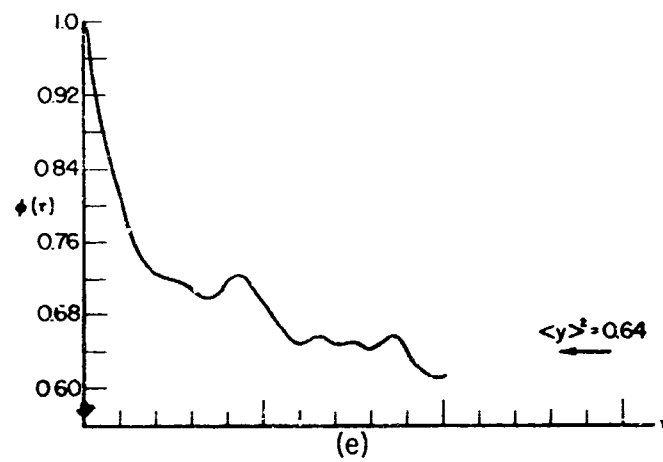
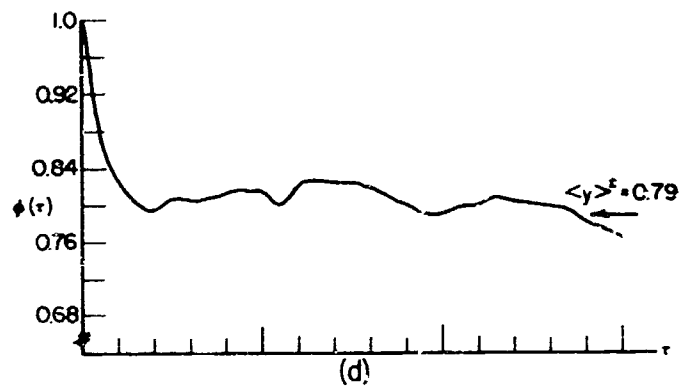


Fig. 9. ACF of Echo II reflected signals. Revolution 3483.

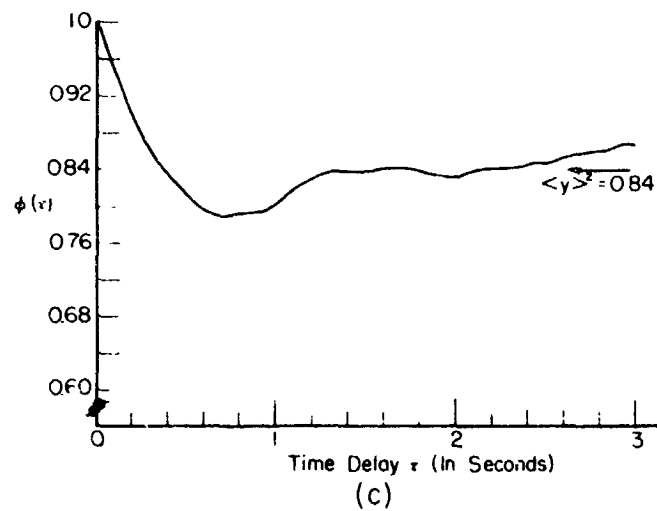
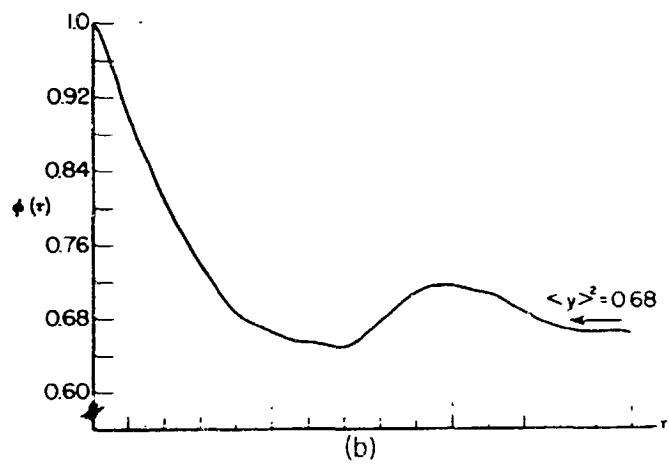
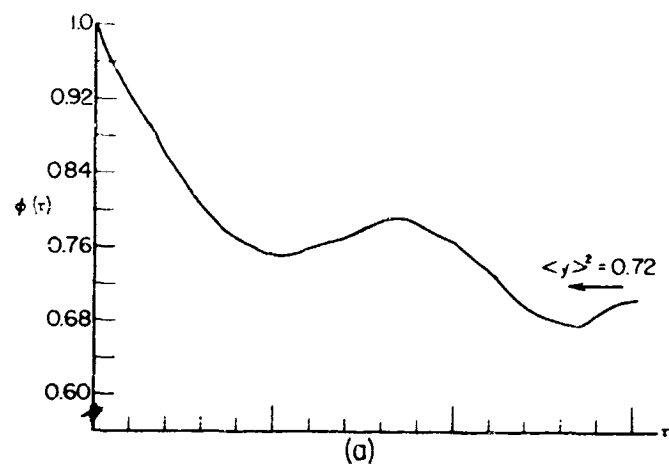


Fig. 10. ACF of Echo I reflected signals. Revolution 18,166.

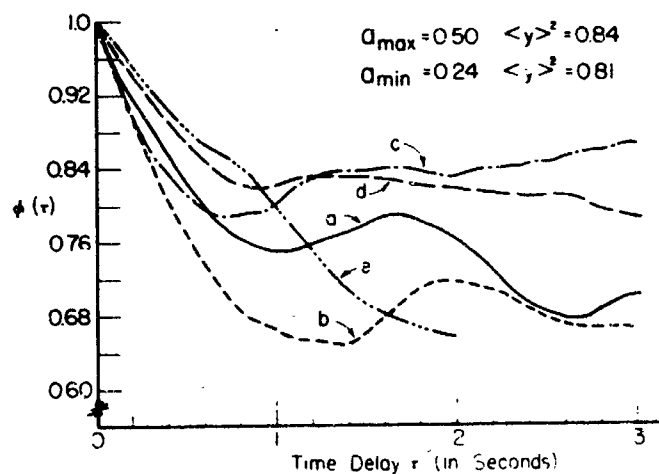
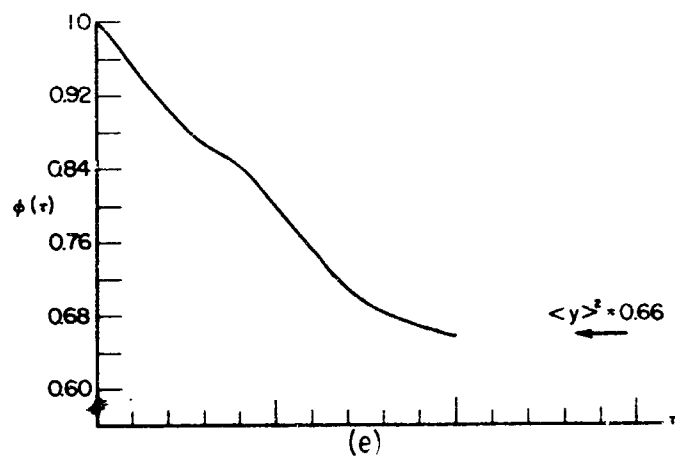
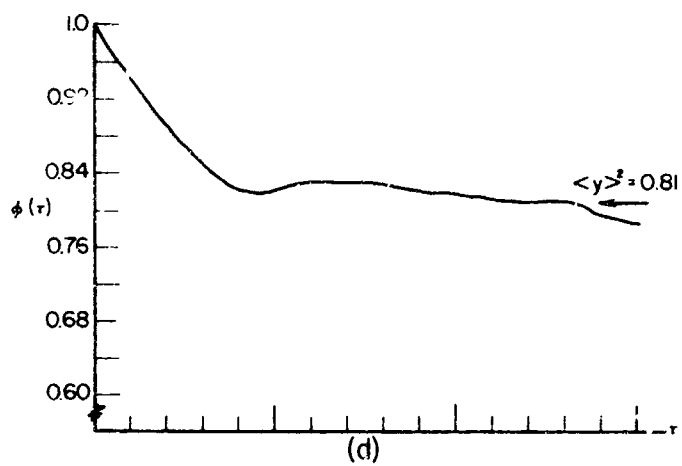


Fig. 10. ACF of Echo I reflected signals. Revolution 18,166.

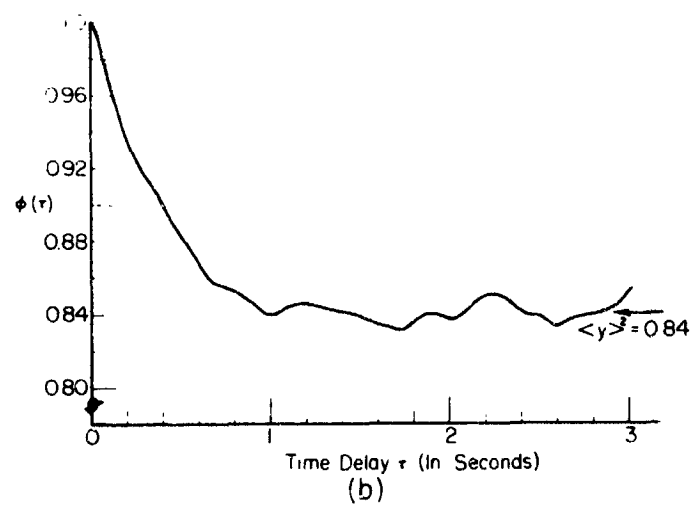
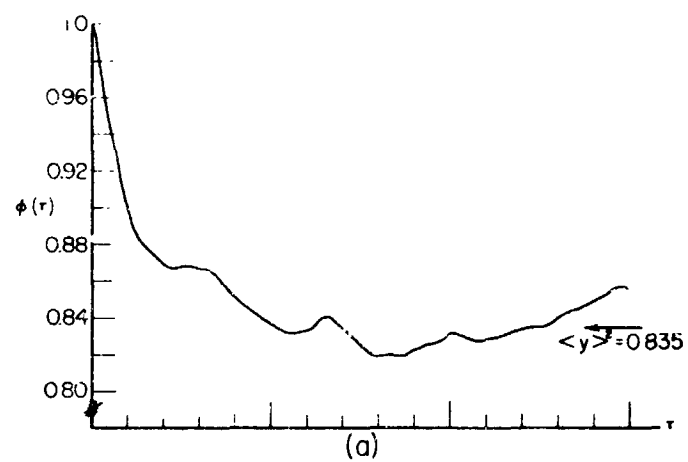


Fig. 11. ACF of Echo I reflected signals. Revolution 18,966.

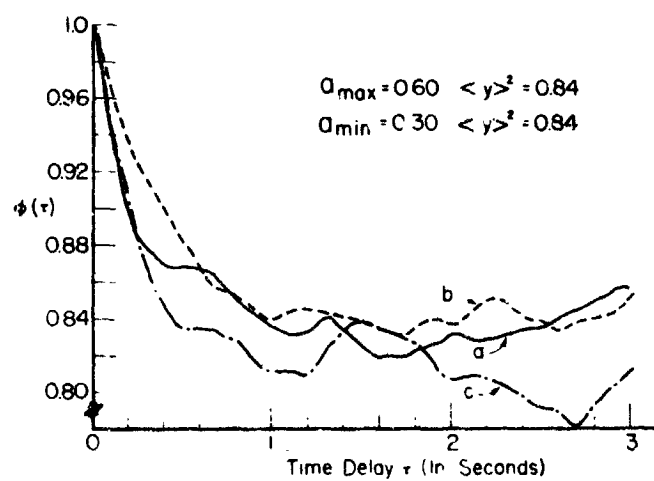
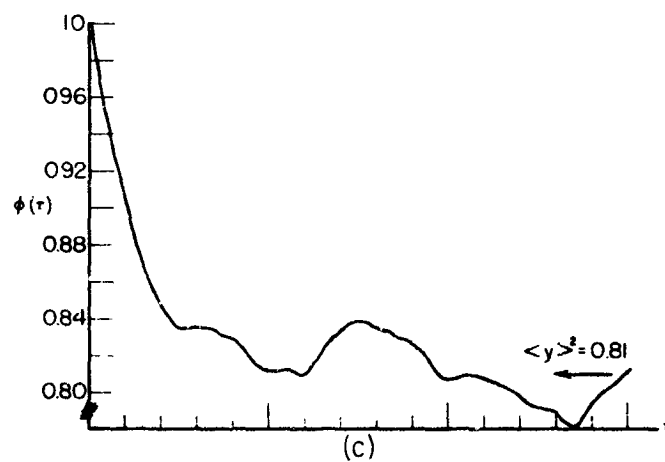


Fig. 11. ACF of Echo I reflected signals. Revolution 18,966.

ACKNOWLEDGMENTS

Thanks are due Dr. Jon W. Eberle for his helpful discussions on the properties of Echo-reflected signals, and to Dr. R.T. Compton, Jr. for his assistance in reading the manuscript. This report would not have been possible without the fine cooperation of the members of the Tracking Team: R.C. Taylor, D.D. Hayes, K. Reinhard, D. Landis, and M. Gordon; and of those in data reduction: F. Cook, R. Christen, and R. Weber. I also thank J. Tourdot for his bringing Reference 6 to my attention.

REFERENCES

1. Eberle, J.W., "An Adaptively Phased. Four-Element Array of Thirty-Foot Parabolic Reflectors for Passive (Echo) Communication Systems," PGAP, Vol. AP-12, No. 2, pp. 169-176, March, 1964.
2. Eaker, H.L., Experiments Plan Passive Communications Satellite, Goddard Space Flight Center, NASA, Greenbelt, Maryland.
3. Zolnay, S.L., "Power Spectral Density of Echo II Reflected Signals," Report 1878-5, 31 December 1964, Antenna Laboratory, The Ohio State University Research Foundation; prepared under Contract Number NAS5-9507 for National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland.
4. Eberle, J.W. and Zolnay, S.L., "Autocorrelation Functions of Echo II Reflected Signals," TDR III, Vol. 2, 1 January 1965, Antenna Laboratory, The Ohio State University Research Foundation; prepared under Contract Number AF 30(602)-2166 for Rome Air Development Center.
5. Solodovnikov, V.N., Introduction to the Statistical Dynamics of Automatic Control Systems, Dover Publications, Inc., N.Y., 1960, pp. 112-116.
6. Davenport, W.B., Jr., Johnson, R.A., and Middleton, D., "Statistical Errors in Measurement on Random Time Functions," Journal of Applied Physics, 23, No. 4, pp. 377-388, April, 1952.